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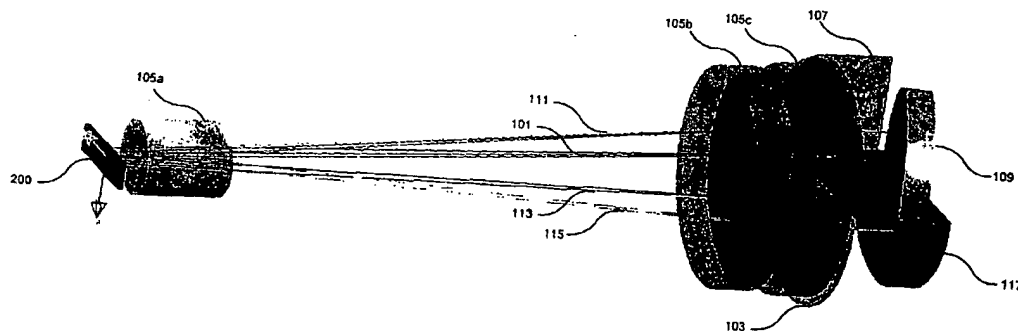
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(54) Title: LITTROW GRATING BASED RECONFIGURABLE OPTICAL ADD/DROP SYSTEM



(57) Abstract: A multi-channel optical switching system particularly usable as a programmable optical add/drop multiplexer in a multi-wavelength communication system. The switching system uses a grating (109) operating at Littrow that separates a multi-channel optical signal (101) into a plurality of optical channels, and combines a plurality of optical channels into a multi-channel optical signal. The system also uses a plurality of optical ports optically coupled to the grating (109) and selecting device to select which optical channel is directed to which of the optical ports.

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## LITTROW GRATING BASED RECONFIGURABLE OPTICAL ADD/DROP SYSTEM

### FIELD OF THE INVENTION

5 This invention relates to the field of optical communications, and more particularly, to a reconfigurable optical add/drop system for use in optical multiplexing.

### BACKGROUND OF THE INVENTION

For several decades, fiber optics have been used for communication.

10 Specifically, fiber optics are used for data transmission and other telecommunication applications. Despite the enormous information carrying capacity of fiber, as compared to conventional copper cable, the high cost of installing fiber optics presents a barrier to full implementation of fiber optics, particular as the "last mile", from the central office to residences and businesses.

15 One method of increasing carrying capacity without incurring additional installation costs has been to multiplex multiple signals onto a single fiber using various methods, such as time division multiplexing, where two or more different signals are carried over the same fiber, each sharing a portion of time. Another, more preferred multiplexing method is wavelength division multiplexing (WDM), where two or more  
20 different wavelengths of light are simultaneously carried over a common fiber.

Until recently, typical fibers used for communications applications had preferred wavelength bands centered at 850 nm, 1300 nm, and 1550 nm, wherein each band typically had a useful bandwidth of approximately 10 to 40 nm depending on the application. Transmission within these bands was preferred by systems designers  
25 because of low optical attenuation. Recent advances in fiber design now provides fiber that have low attenuation over a very broad transmission range, from 1300-1620 nm.

Wavelength division multiplexing can separate a fiber's bandwidth into multiple channels. Dividing bandwidth into multiple discreet channels, such as 4, 8, 16, 40, or even as many as 160 channels, through a technique referred to as dense channel  
30 wavelength division multiplexing (DWDM), is a relatively lower cost method of substantially increasing telecommunication capacity, using existing fiber optic transmission lines. Techniques and devices are required, however, for multiplexing the different discreet carrier wavelengths. That is, the individual optical signals must be combined onto a common fiber-optic line or other optical waveguide and then later  
35 separated again into the individual signals or channels at the opposite end or other point along the fiber-optic cable. Thus, the ability to effectively combine and then separate individual wavelengths (or wavelength sub-ranges) is of growing importance to the fiber-optic telecommunication's field and other fields employing optical instruments.

1       Optical multiplexers are known for use in spectroscopic analysis equipment and  
for the combination or separation of optical signals in wavelength division multiplexed  
fiber-optic telecommunications systems. Known devices for this purpose have  
employed, for example, diffraction gratings, prisms and various types of fixed or tunable  
5 filters.

Approaches for selectively removing or tapping a channel, i.e., selective  
wavelengths, from a main trunk line carrying multiple channels, i.e., carrying optical  
signals on a plurality of wavelengths or wavelength sub-ranges, is suggested, for  
example, in U.S. Pat. No. 4,768,849 to Hicks, Jr. Hicks, shows filter taps, as well as the  
10 use of gangs of individual filter taps, each employing high performance, multi-cavity  
dielectric pass-band filters and lenses for sequentially removing a series of wavelength  
sub-ranges or channels from a main trunk line. The filter tap of Hicks, returns a  
multi-channel signal to the main trunk line as it passes the desired channel to a branch  
line. One known demux is disclosed in Pan et al., US Pat. No. 5,652,814, Figure 25. In  
15 Pan et al., the WDM input signal is cascaded through individual filter assemblies,  
consisting of a fiber collimator, thin film filter, and a fiber focusing lens. Each filter is set  
for a given wavelength. However, aligning the fibers for each wavelength is costly and  
errors in the alignment contribute significantly to the system losses. Further, Figure 13  
of Pan et al. teaches the use of a dual fiber collimator, thin film filter, and a dual fiber  
20 focusing lens to selectively DROP and ADD a single wavelength or range of  
wavelengths. As discussed above, aligning the collimators is expensive.

Polarization dependent loss (PDL) is also a problem in WDM system because  
the polarization of the light drifts as it propagates through the fiber and furthermore this  
drift changes over time. Thus, if there is PDL in any component, the drifting polarization  
25 will change the signal level, which may degraded the system operation.

Other multiplexer devices may be employed to add or drop channels in WDM  
systems. These systems are commonly known as optical add/drop multiplexers, or  
OADM. Another OADM, disclosed by Mizrahi US Pat. No. 6,185,023, employs fiber  
Bragg gratings to demux and mux signals in a WDM system. This method requires  
30 optical circulators and multiple components.

However, the multi channel OADM designs discussed above are not  
programmable by the end user. That is, each multiplexers is designed and  
manufactured to mux (add) specific channels; or when used in reverse each  
multiplexers is also designed and manufactured to demux (drop) specific channels. This  
35 limitation mandates that the optical system's parameters be fixed before installation.  
Changes are not possible without replacing the fixed optical multiplexers with different  
designed multiplexers. This is expensive.

One known programmable OADM is discussed in Boisset et al, International  
Publication No. WO01/13151. In Boisset et al., the desired add/drop channel is

1 programmed by translating a segmented filter. To achieve this translation however, a  
large mechanical mechanism is employed. A further limitation to Boisset et al. is that  
only a single channel may be added or dropped per device. Designers may employ  
multiple devices, deployed in series, and programmed as necessary to add/drop the  
5 correct channel; however, this approach requires multiple devices and has multiple  
points of failure. Furthermore, the size of such a device would be overly large and  
therefore not practical for many applications where space is limited.

Two other programmable OADM's are disclosed by Tomlinson, US Pat.  
No. 5,960,133, and Aksyuk, et al, US Pat. No. 6,204,946, both use bulk optics and  
10 gratings to demultiplex and multiplex WDM input and output signal. While OADM's  
disclosed by Tomlinson and Aksyuk are both programmable, neither provides for  
discrete adding or dropping of an individual optical signal in a multi signal system. To  
achieve discrete adding or dropping of an individual optical signal in a multi signal  
system using the systems disclosed in Tomlinson and Aksyuk, additional components  
15 are required. All the Add wavelengths must be multiplexed onto a single fiber before it  
is sent to the OADM. Likewise, a demultiplexer must be added to the Drop port to  
access the individual wavelength channels. The additional components require  
additional space, add attenuation, and add cost to the system.

It is an object of the present invention to provide improved optical multiplexing  
20 devices which reduce or wholly overcome some or all of the aforesaid difficulties  
inherent in prior known devices. Particular objects and advantages of the invention will  
be apparent to those skilled in the art, that is, those who are knowledgeable and  
experienced in this field of technology, in view of the following disclosure of the  
invention and detailed description of certain preferred embodiments.

25

## SUMMARY OF THE INVENTION

In accordance with a first aspect of the invention, a programmable Littrow grating  
based optical add/drop multiplexing device, programmed to add and/or drop one or  
more optical channels from/to a multi-channel light signal, comprises a focal plane, in  
30 combination with a lens in combination with a prism, a Littrow grating, and a plurality of  
programmable mirrors.

The focal plane further comprises an IN port for receiving a multi-channel optical  
signal, a PASS port for transmitting a multi-channel optical signal, a plurality of ADD  
ports for receiving a plurality of optical channels, a plurality of DROP ports for  
35 transmitting a plurality of optical channels, and a plurality of programmable mirrors for  
directing light channels.

The multi-channel light enters the device by way of the IN port and is directed  
through the Lens to the Littrow grating, where selected channels are dispersed and  
directed through the lens and focused onto to the plurality of programmable mirrors.

- 1 The Littrow grating separates the multi-channel optical signal into its individual optical channels and directs the individual optical channels through the Prism, the Lens, and onto the programmable mirror that corresponds with that individual channel.

Depending upon the programmed state of the mirrors, the channels are either  
5 directed through the lens, prism, and Littrow grating (or another wavelength separating medium) which combine the channels into a multi-channel light signal and directs it out of the system by way of the prism, lens and pass port, or the channels are directed through the lens, and mirror so as to exit the system by way of the Lens and one of the plurality of drop ports.

- 10 In the instance where the programmed state of the mirrors directs one or more channels through one of the plurality of drop ports, one or more channels may enter the device by way of one of the plurality of add ports, and are directed through the lens, mirror, and lens, to the one of the plurality of programmable mirrors so as to exit the system by way of the lens, prism, and Littrow grating, which combines the channels into  
15 a multi-channel light signal and directs it out of the system by way of the prism, lens and pass port.

To reduce polarization dependent loss (PDL) in the system a quarter-wave plate (QWP) may also be employed between the Lens and Littrow grating. The QWP rotates the polarization so that light that is s-polarized on the first pass is p-polarized on the  
20 second pass and there is no net polarization dependent loss (PDL) for light traveling between the IN and PASS ports.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a first embodiment of a Littrow grating based  
25 OADM detailing the various channel paths through the device.

Fig. 2 is a perspective view of the Focal Plane of the embodiment of Fig. 1.

Fig. 3 is a schematic view of a Focal Plane for an eight-channel embodiment of a Littrow grating based OADM.

Fig. 4 is a schematic side view of a MEMS mirror in IN/PASS and DROP/ADD  
30 modes.

Fig. 5 is a perspective view of the embodiment of Fig. 1 detailing the channel paths through the device for an PASS channel.

Fig. 6 is a perspective view of the embodiment of Fig. 1 detailing the channel paths through the device for an DROP channel.

35 Fig. 7 is a perspective view of the embodiment of Fig. 1 detailing the channel paths through the device for an ADD channel.

## 1 DETAILED DESCRIPTION OF THE INVENTION

The Littrow grating based OADM of the invention has numerous applications, including use in fiber optic telecommunications systems. For purposes of illustration, the preferred embodiments described below in detail multiplexing and demultiplexing, and adding and dropping channels, in wavelength division multiplexing and demultiplexing for a multi-channel fiber optic telecommunication systems. Exemplary references to an optical channel, or simply to a channel, should be understood to mean an optical signal with a centered wavelength and an upper and lower wavelength. Channel spacing is measured from the center of the first channel to the center of an adjacent channel.

A three channel Littrow grating based OADM, employing one embodiment of the invention, is detailed in Fig. 1. It is of note that while only three channels are used in this example, a substantially larger number of channels/ports may be employed. The Littrow grating based OADM allows for demultiplexing and multiplexing separate optical channels onto or off of a multi-channel light signal. The OADM of Fig. 1 may be dynamically programmed to demultiplex and multiplex any combination of channels onto or off the multi-channel light signal.

A first embodiment of the programmable OADM device of Fig. 1 comprises a focal plane 200 in combination with Lens 105, a prism 107, and a Littrow grating 109. The device of Fig. 1 may be mounted within an enclosure optimized for optical transmission, including a gas-filled enclosure, or the like.

A Littrow grating is a grating that operates at or near Littrow. Littrow is a special, but common case, in which the light is diffracted off the grating back toward the direction from which it came (i.e.,  $a = b$ ); this is called the Littrow configuration, for which the grating equation becomes:

$$m\lambda = 2d \sin(a)$$

where  $a$  is the incident angle,  $b$  is the diffracted angle,  $m$  is the grating order,  $\lambda$  is the wavelength, and  $d$  is the grating groove spacing. In one embodiment, the grating is used near the Littrow condition, so the same lens can be used for collimating and focusing the light. Further, using the grating near the Littrow condition takes advantage of the high diffraction efficiency of the grating near the Littrow condition.

Lens 105 may be comprised of multiple lens elements 105a, 105b and 105c. It is well known in the art that a lenses may be comprised of multiple lens elements to achieve a particular optical prescription.

Prism 107 may optionally be used in any embodiment of the system. Temperature changes cause grating to expand and contract. As gratings expand and contract the wavelength-sized gradations that cause diffraction increase and decrease

1 causing a change in the diffraction angle from a grating. Prism 107 may be used to minimize the thermal affects on Grating 109. When Prism 107 and Grating 109 are properly designed and configured the effects of temperature on the system are greatly reduced. However, some embodiments of the system do not contain Prism 107.

5 Quarter-wave plate (QWP) 103 may also be employed between the Lens and Littrow grating to reduce polarization dependent loss (PDL) in the system a . The QWP 103 rotates the polarization so that light that is s-polarized on the first pass is p-polarized on the second pass and there is no net polarization dependent loss (PDL) for light traveling between the IN and PASS ports.

10 The focal plane 200 of Fig. 2 further comprises an IN port 201 for receiving a multi-channel optical signal 101, a PASS port 203 for transmitting a multi-channel optical signal, a plurality of ADD ports 213, 223, and 233, for receiving a plurality of optical channels, a plurality of DROP ports 215, 225, 235, for transmitting a plurality of optical channels, and a plurality of Programmable Mirrors 211, 221, 231, for directing light  
15 channels. Each DROP and ADD port is for a preassigned wavelength. All of these component are precisely aligned with each other, and mounted together so as to accommodate the entrance and exit of optical signals. Larger focal planes may be constructed and an eight channel system's focal plane is depicted in Fig. 3 comprising an IN port 301 for receiving a multi-channel optical signal 101, a PASS port 303 for  
20 transmitting a multi-channel optical signal, a plurality of ADD ports 313, 323, 333, 343, 353, 363, 373, 383 for receiving a plurality of optical channels, a plurality of DROP ports 315, 325, 335, 345, 355, 365, 375, 385 for transmitting a plurality of optical channels, and a plurality of Programmable Mirrors 311, 321, 331, 341, 351, 361, 371, 381 for directing light channels.

25 Turning again to Fig. 1, as well as to Fig. 2, a multi-channel light signal 101 enters the device through the IN port 201 on the focal plane 200, and is directed through Lens 105. The multi-channel light signal 101 is directed through the Lens 105, QWP 103, Prism 107, and Littrow grating 109. The Littrow grating 109 diffracts the individual channels of the multi-channel light signal 101 (hereafter channels) towards  
30 the Lens 105, QWP 103, to the channel's associated Programmable Mirror 211, 221, or 231.

Depending upon the programmed state of the Programmable Mirrors channels received via the IN port 201 are either passed via the PASS port 203 or dropped via one of the plurality of DROP ports 215, 225, or 235. In the event one or more channels  
35 received via the IN port 201 are passed via PASS port 203, the channel(s) are directed through the Lens 105, QWP 103, Prism 107, and Littrow grating 109 which multiplexes the channel with other passed and added channels into a multi-channel light signal 111

1 and directs it out of the system by way of the Prism 107, QWP 103, Lens 105 and PASS port 203.

In the event one of more channels received via the IN port 201 are dropped via one of the plurality of DROP ports 215, 225, or 235, the channel(s) are directed through  
5 the Lens 105, and mirror 117 so as to exit the system by way of the Lens 105 and one of the plurality of DROP ports 215, 225, or 235 corresponding to the channel. Because the mirrors may be programmed individually, it will be clear to one skilled in the art that any channel may be dropped or passed.

In the instance where one or more of the received via the IN port 201 are  
10 dropped via one of the plurality of DROP ports 215, 225, or 235, one or more channels corresponding channels may enter the device through one of the plurality of ADD ports 213, 223, or 233. These added channels enter the system by way of one of the plurality of ADD ports 213, 223, or 233, and are directed through the Lens 105, Lens 105, mirror 117, Lens 105, to the one of the plurality of Programmable Mirrors  
15 corresponding to the channel so as to exit the system by way of the Lens 105, QWP 103, Prism 107, and Littrow grating 109, which multiplexes the channel with other passed and added channels into a multi-channel light signal 111 and directs it out of the system by way of the Prism 107, QWP 103, Lens 105 and PASS port 203.

Turning to Fig. 4, in one embodiment the Programmable Mirrors 401 and 403 are  
20 constructed using Micro Electrical Mechanical Systems (MEMS). Programming of the Programmable Mirrors 401 and 403 is achieved by applying an electrical signal to the MEMS mirror. The Programmable Mirror 401 is programmed to reflect the IN port to the PASS port. The Programmable Mirror 403 is programmed to reflect the IN port to the DROP port, and to reflect the ADD port to the PASS port. A larger mirror may be  
25 employed by design to control more than one channel. Of course, other types of mirror actuators could be used.

By engaging the channel mirrors, one or more separate channels may be dynamically routed onto or off of a multi-channel light signal. Further, by engaging the channel mirrors as a function of time and in synchronous conjunction with other system  
30 components, time-division multiplexing of optical signals may be achieved.

One or more quarter-wave plates (QWP) may be employed in the system to reduce polarization dependent loss (PDL) in the system. The preferred location of the QWP is between Lens 105 and Grating 109. QWP may be positioned such that they are substantially normal to the propagating light beam and the retardance axis is at 45  
35 degrees to the light that is polarized parallel and perpendicular to the grating graduations. Passage through the QWP converts the parallel and perpendicular polarized components of the light into right and left circularly polarized states.



- 1 Reflection off the grating converts changes the handedness of the polarization: right  
circularly polarized light into left circularly polarized light and visa versa. Passage  
through the QWP the second time converts the light back to a linearly polarized state,  
but it's departing polarization state is orthogonal to the input state. Thus, during one  
5 pass through the system the light is parallel and on the next is perpendicular leaving a  
substantially zero PDL for the system.

Consider again the three channel system depicted in Fig. 1, where the multi-  
channel light signal contains:

- channel one - which is to be passed via PASS port 203;  
10 channel two - which is to be dropped via DROP port 225;  
no channel three comes into the system; and  
a channel three is added via ADD port 233 and passed via PASS port  
203.

Table 1 details the desired channel operation (i.e., PASS, DROP, ADD, etc.) for each  
15 channel, as well as the Programmable Mirror's state.

Table 1

CHANNEL	MODE	MIRROR STATE
One	PASS	IN to PASS
Two	DROP	In to DROP
Three	ADD	ADD to PASS

25 An optical prescription for a three channel Littrow grating based OADM is  
provided in Table 2 in CODE V format. The numerical aperture of the lens is 0.17 to  
accommodate standard fiber and the grating has 600 lp/mm. The root mean square  
wavefront error is less than 0.03 waves in double pass over the temperature range of  
-20 to +70 degrees centigrade, when the mount is made of 416 Stainless Steel.

30

35

1 Table 2

	RADIUS	THICKNESS	RMD	GLASS
OBJ:	INFINITY	5.584779		
1:	-62.78788	16.838678		SF11_SCHOTT
2:	-39.52723	96.862455		AIR
3:	-109.42245	1.700000		NSF15_SCHOTT
4:	76.61669	7.195070		NBAK1_SCHOTT
5:	-58.64552	0.100000		AIR
6:	520.40928	1.700000		NBK10_SCHOTT
7:	48.24900	6.885228		NBAK1_SCHOTT
8:	-199.75265	0.100000		AIR
9:	INFINITY	10.148101		NBK7_SCHOTT
10:	INFINITY	2.885689		AIR
10 ADE:	-22.806501	BDE: 0.000000	CDE: 0.000000	DAR
STO:	INFINITY	-50.000000	REFL	AIR
GRT:				
GRO:	-1	GRS: 0.001667		
GRX:	0.000000	GRY: 1.000000	GRZ: 0.000000	
ADE:	-15.353235	BDE: 0.000000	CDE: 0.000000	

15

Turning next to Fig. 5 and Fig. 2, the path of channel one of the three channel multi-channel collimated light signal 101 is more clearly illustrated. Recall that channel one is to be received and PASSED by the system as follows. The multi-channel light signal 101 enters the device through the IN port 201 and is directed through the Lens 105, Prism 107, and Littrow grating 109. Littrow grating 109 demultiplexes the channels of the Multi-channel light signal 101 and diffracts channel one 501 through the Prism 107 and Lens 105 to Programmable Mirror 211. The state of Programmable Mirror 211 is set to "IN to PASS" and therefore reflects channel one 501 through Lens 105, Prism 107 to Grating 109. Grating 109 multiplexes channel one 501 with other passed and added channels into a multi-channel light signal 111 and directs multi-channel light signal 111 out of the system by way of the Prism 107, Lens 105 and PASS port 203.

Turning next to Fig. 6 and Fig. 2, the path of channel two of the three channel multi-channel collimated light signal 101 is more clearly illustrated. Recall that channel two is to be received and dropped by the system. The multi-channel light signal 101 enters the device through the IN port 201 and is directed through the Lens 105, Prism 107, and Littrow grating 109. Littrow grating 109 demultiplexes the channels of the Multi-channel light signal 101 and diffracts channel two 601 through the Prism 107 and Lens 105 to Programmable Mirror 221. The state set to "IN to DROP" and therefore reflects channel two 601 through Lens 105, to Mirror 117. Mirror 117 reflects channel two 601 out of the system by way of Lens 105 and DROP port 225.

1       Turning next to Fig. 7 and Fig. 2, the path of channel three of the three channel  
multi-channel collimated light signal 101 is more clearly illustrated. Recall that the  
multi-channel light signal 101 does not contain a channel three, but instead, channel  
three is added multi-channel light signal 111 directed out of the system. Channel three  
5       701 enters the device through ADD 233 and is directed through the Lens 105, and  
Mirror 117. Mirror 117 reflects channel three to Programmable Mirror 231 by way of  
Lens 105. The state of Programmable Mirror 231 is set to "ADD to PASS" and therefore  
reflects channel three through Lens 105, Prism 107 to Grating 109. Grating 109  
multiplexes the channel with other passed and added channels into a multi-channel  
10       light signal 111 and directs multi-channel light signal 111 out of the system by way of  
the Prism 107, Lens 105 and PASS port 203.

      Having thus described exemplary embodiments of the present invention, it  
should be understood by those skilled in the art that the above disclosures are  
exemplary only and that various other alternatives, adaptations and modifications may  
15       be made within the scope of the present invention. The presently disclosed  
embodiments are to be considered in all respects as illustrative and not restrictive. The  
scope of the invention being indicated by the claims, rather than the foregoing  
description, and all changes which come within the meaning and range of equivalency  
of the claims are therefore intended to be embraced therein.

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## 1 WHAT IS CLAIMED IS:

1. A multi-channel optical switching system, comprising:  
an in port receiving a first multi-channel optical signal;  
a wavelength separating medium separating the first multi-channel optical signal  
5 into a first plurality of single-channel optical signals, and combining a second plurality of  
single-channel optical signals into a second multi-channel optical signal;  
a pass port transmitting the second multi-channel optical signal;  
a plurality of drop ports transmitting at least one of the first plurality of single-  
channel optical signals;  
10 a plurality of add ports receiving at least one of the second plurality of single-  
channel optical signals;  
means for directing at least one of the first plurality of single-channel optical  
signals on to at least one of the plurality of drop ports, and for directing at least one of  
the second plurality of single-channel optical signals on to a second optical path  
15 directed to the pass port.  
a lens element optically between the means for directing and the wavelength  
separating medium; and  
a mirror reflecting at least one of the first plurality of single-channel optical  
signals to the at least one of the plurality of drop ports, and reflecting at least one of the  
20 second plurality of single-channel optical signals to the means for directing.
2. The multi-channel optical switching system of claim 1, further comprising a  
polarization dependent optical component optically between the wavelength  
separating medium and the lens element.
- 25 3. The multi-channel optical switching system of claim 2, wherein the polarization  
dependent optical component is a quarter wave plate.
4. The multi-channel optical switching system of claim 1, wherein the wavelength  
30 separating medium is a grating.
5. The grating of claim 4, wherein the grating is operating at Littrow.
6. The multi-channel optical switching system of claim 1, further comprising a prism  
35 optically coupled to the wavelength separating medium.

- 1 7. The multi-channel optical switching system of claim 1, wherein the lens element is optically between the means for directing and the mirror.
8. The multi-channel optical switching system of claim 1, wherein each of the  
5 plurality of drop ports corresponds with one of the first plurality of single-channel optical signals.
9. The multi-channel optical switching system of claim 1, wherein each of the plurality of add ports corresponds with one of the second plurality of single-channel  
10 optical signals.
10. The multi-channel optical switching system of claim 1, wherein the in port, the pass port, the plurality of drop ports, the plurality of add ports, and the means for directing are located on a focal plan.
- 15 11. The multi-channel optical switching system of claim 1, wherein the means for directing is at least one of a plurality of programmable mirrors.
12. A multi-channel optical switching system, comprising:  
20 an in port receiving a first multi-channel optical signal;  
a wavelength separating medium separating the first multi-channel optical signal into a first plurality of single-channel optical signals, and combining a second plurality of single-channel optical signals into a second multi-channel optical signal;  
a pass port transmitting the second multi-channel optical signal;  
25 a plurality of add ports receiving at least one of the second plurality of single-channel optical signals;  
means for directing at least one of the second plurality of single-channel optical signals on to a second optical path directed to the pass port.  
a lens element optically between the means for directing and the wavelength  
30 separating medium; and  
a mirror reflecting at least one of the second plurality of single-channel optical signals to the means for directing.
13. The multi-channel optical switching system of claim 12, further comprising a  
35 polarization dependent optical component optically between the wavelength separating medium and the lens element.

- 1 14. The multi-channel optical switching system of claim 13, wherein the polarization dependent optical component is a quarter wave plate.
15. The multi-channel optical switching system of claim 12, wherein the wavelength  
5 separating medium is a grating.
16. The grating of claim 15, wherein the grating is operating at Littrow.
17. The multi-channel optical switching system of claim 12, further comprising a  
10 prism optically coupled to the wavelength separating medium.
18. The multi-channel optical switching system of claim 12, wherein the lens element is optically between the means for directing and the mirror.
- 15 19. The multi-channel optical switching system of claim 12, wherein each of the plurality of add ports corresponds with one of the second plurality of single-channel optical signals.
20. The multi-channel optical switching system of claim 12, wherein the in port, the  
20 pass port, the plurality of add ports, and the means for directing are located on a focal plan.
21. The multi-channel optical switching system of claim 12, wherein the means for directing is at least one of a plurality of programmable mirrors.
- 25 22. A multi-channel optical switching system, comprising:  
an in port receiving a first multi-channel optical signal;  
a wavelength separating medium separating the first multi-channel optical signal into a first plurality of single-channel optical signals, and combining a second plurality of  
30 single-channel optical signals into a second multi-channel optical signal;  
a pass port transmitting the second multi-channel optical signal;  
a plurality of drop ports transmitting at least one of the first plurality of single-channel optical signals;  
means for directing at least one of the first plurality of single-channel optical  
35 signals on to at least one of the plurality of drop ports.  
a lens element optically between the means for directing and the wavelength separating medium; and

- 1 a mirror reflecting at least one of the first plurality of single-channel optical signals to the at least one of the plurality of drop ports to the means for directing.
23. The multi-channel optical switching system of claim 22, further comprising a  
5 polarization dependent optical component optically between the wavelength separating medium and the lens element.
24. The multi-channel optical switching system of claim 23, wherein the polarization dependent optical component is a quarter wave plate.
- 10 25. The multi-channel optical switching system of claim 22, wherein the wavelength separating medium is a grating.
26. The grating of claim 25, wherein the grating is operating at Littrow.
- 15 27. The multi-channel optical switching system of claim 22, further comprising a prism optically coupled to the wavelength separating medium.
28. The multi-channel optical switching system of claim 22, wherein the lens element  
20 is optically between the means for directing and the mirror.
29. The multi-channel optical switching system of claim 22, wherein each of the plurality of drop ports corresponds with one of the first plurality of single-channel optical signals.
- 25 30. The multi-channel optical switching system of claim 22, wherein the in port, the pass port, the plurality of drop ports, and the means for directing are located on a focal plan.
- 30 31. The multi-channel optical switching system of claim 22, wherein the means for directing is at least one of a plurality of programmable mirrors.
32. A multi-channel optical switching system comprising:  
a substrate having a plurality of optical ports, at least one of the optical ports  
35 providing a multi-channel optical signal comprised of a plurality of single-channel optical signals, and a plurality of moveable mirrors;

1 a wavelength separating medium positioned to separate at least some of the  
plurality of single-channel optical signals to some of the moveable mirrors;  
a mirror reflecting at least some of the plurality of optical channel signals; and  
a lens element optically between the substrate and the wavelength separating  
5 medium.

33. The multi-channel optical switching system of claim 32, further comprising a  
polarization dependent optical component optically between the wavelength  
separating medium and the lens element.

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34. The multi-channel optical switching system of claim 33, wherein the polarization  
dependent optical component is a quarter wave plate.

35. The multi-channel optical switching system of claim 32, wherein the wavelength  
15 separating medium is a grating.

36. The grating of claim 35, wherein the grating is operating at Littrow.

37. The multi-channel optical switching system of claim 32, further comprising a  
20 prism optically coupled to the wavelength separating medium.

38. The multi-channel optical switching system of claim 32, wherein the lens element  
is optically between the substrate and the mirror.

25 39. The multi-channel optical switching system of claim 32, wherein each of the  
plurality of ports corresponds with one of the plurality of single-channel optical signals.

40. The multi-channel optical switching system of claim 32, wherein the means for  
directing is at least one of the plurality of moveable mirrors are programmable mirrors.

30

41. In a multi-channel optical switching system comprising a substrate having a  
plurality of optical ports, a plurality of moveable mirrors, a wavelength separating  
medium, a plurality of moveable mirrors, a mirror, and a lens element, the method of  
add/drop multiplexing, comprising:

35 receiving a first multi-channel optical signal comprised of a plurality of single-  
channel optical signals from one of the plurality of optical ports,



1 directing the first multi-channel optical signal to the wavelength separating  
medium where the wavelength separatesmedium separating at least some of the  
plurality of single-channel optical signals from the first multi-channel optical signal;  
directing the separated single-channel optical signals to a respective one of the  
5 plurality of moveable mirrors;  
selectively tilting each of the moveable mirrors between two positions,  
wherein, in the first position, the plurality of moveable mirrors reflects the  
separated single-channel optical signals to a corresponding optical port,  
wherein, in the second position, the plurality of moveable mirrors reflects the  
10 separated single-channel optical signals to a corresponding optical port and reflects  
one or more received single-channel optical signals to the mirror,  
where the mirror reflects the one or more received single-channel optical  
signals to the wavelength separating medium,  
the wavelength separating medium combines the received single-channel  
15 optical signals with one or more separated single-channel optical signals into a  
second multi-channel optical signal and directs the second multi-channel optical  
signal to one of the plurality of optical ports.

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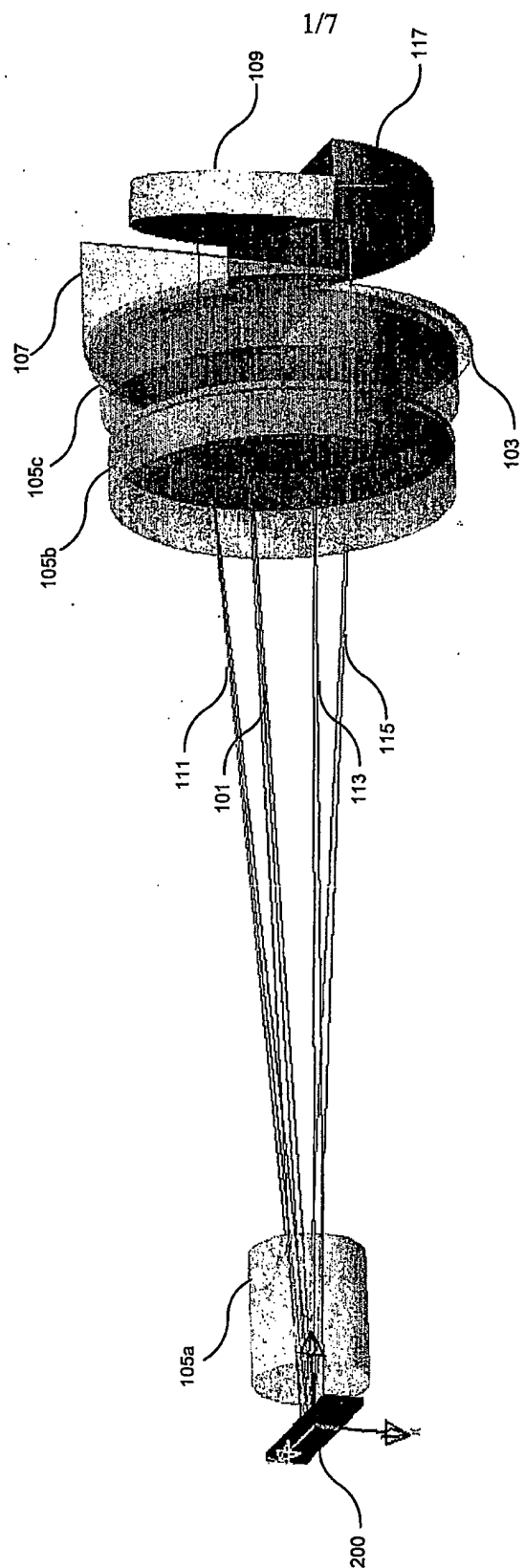


Fig 1

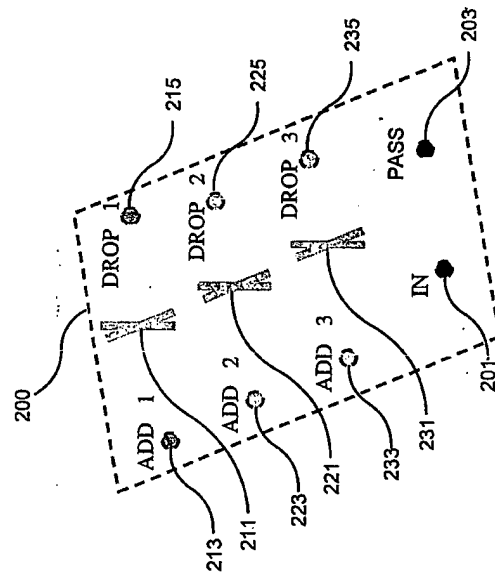


Fig 2

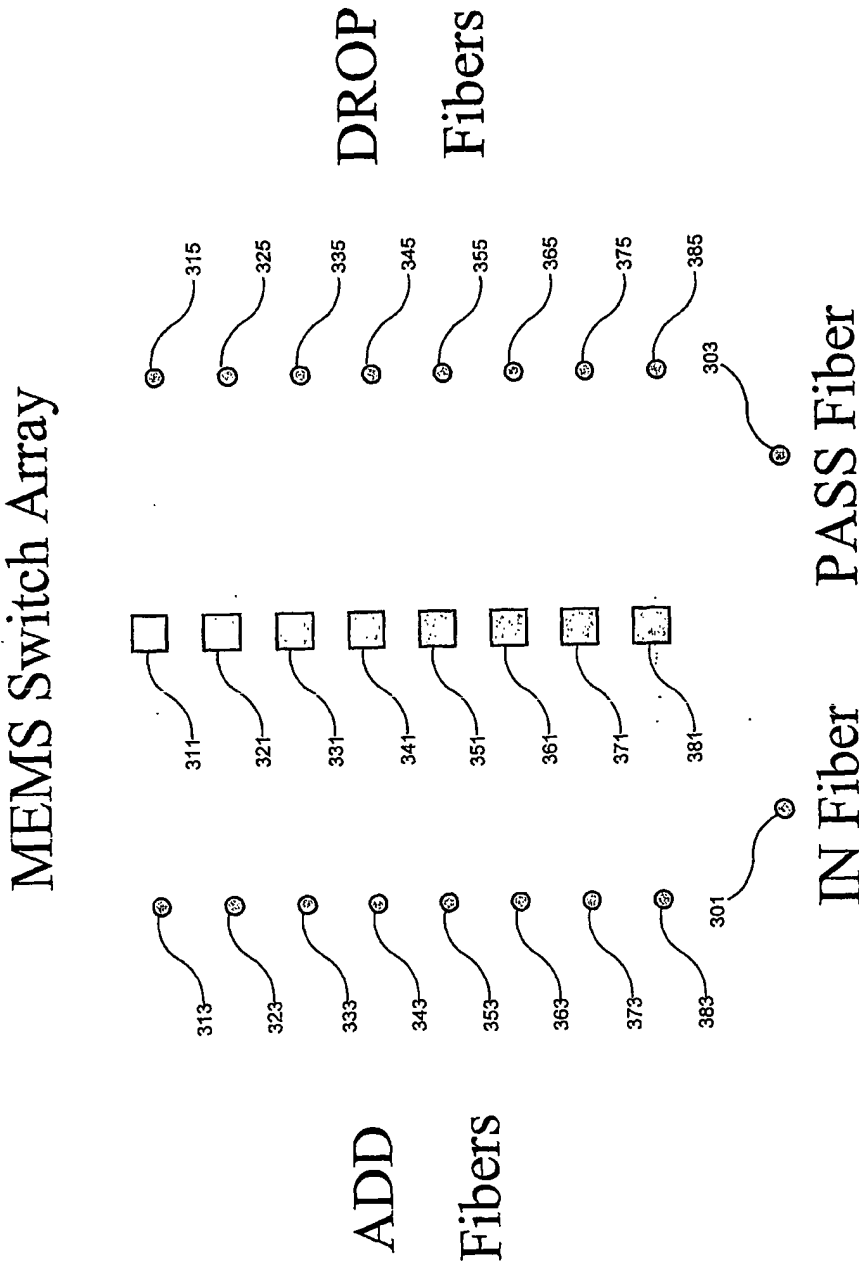


Fig 3

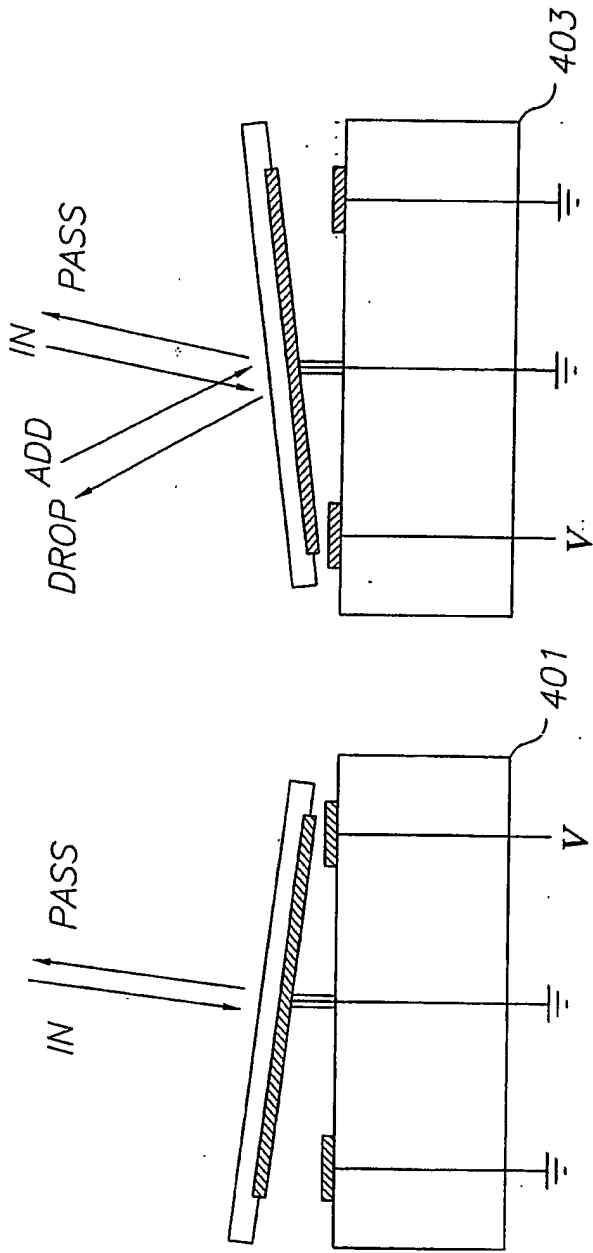


FIG. 4

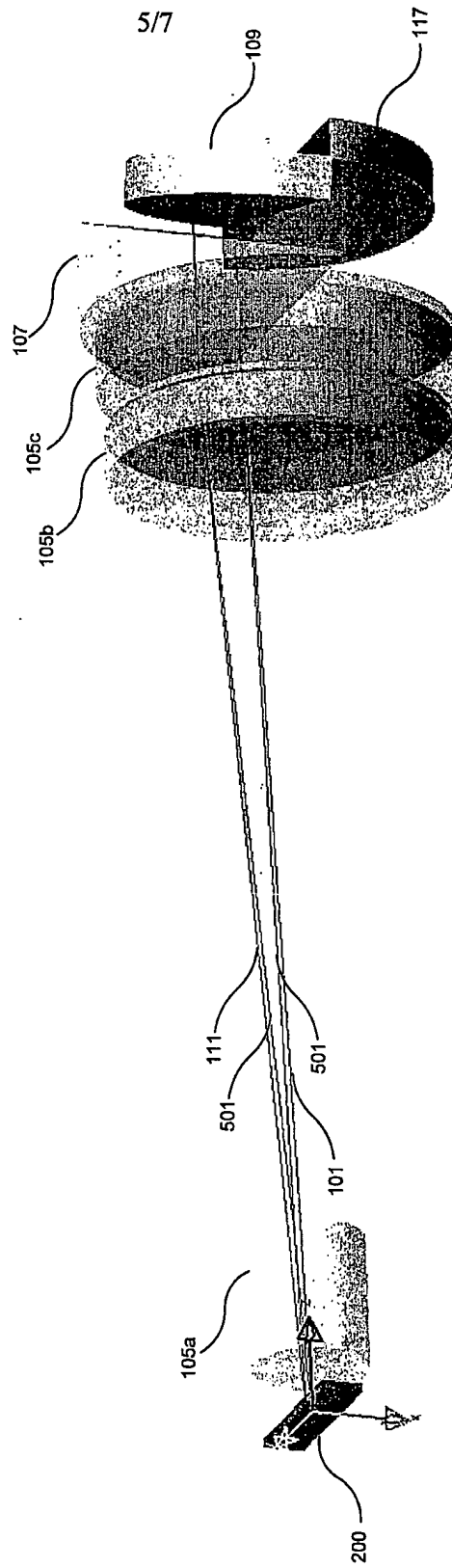


Fig 5

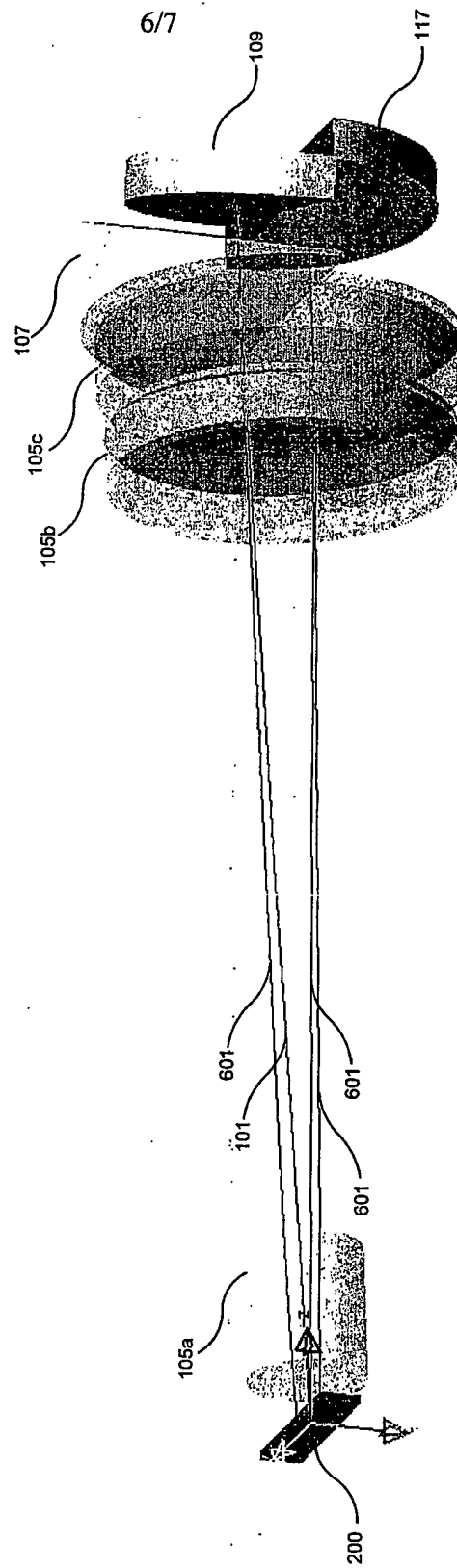


Fig 6

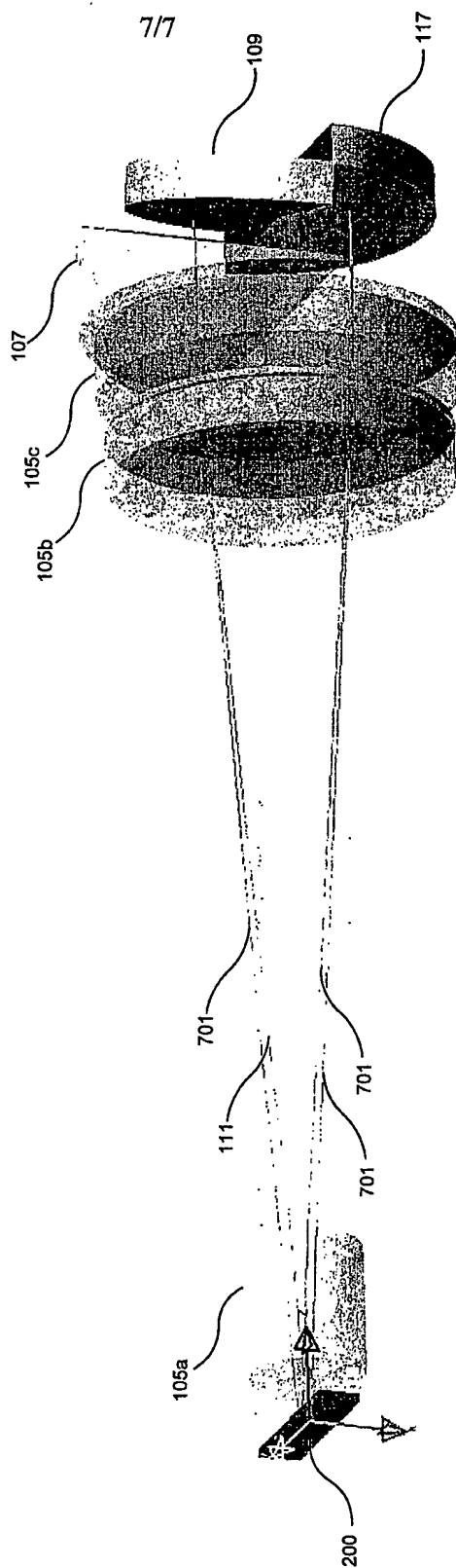


Fig 7



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/31219

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) : GO2B 6/26, 6/42;H04B 10/24;H04J 14/02

US CL : 385/16,18;359/114,124

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 385/11,16-18,24,31,42;359/114,122,124,128

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US 2002/0131698 A1 (WILDE) 19 September 2002 (19.09.2002), see entire reference.	1-41

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.**\* Special categories of cited documents:****"A"** document defining the general state of the art which is not considered to be of particular relevance**"E"** earlier application or patent published on or after the international filing date**"L"** document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)**"O"** document referring to an oral disclosure, use, exhibition or other means**"P"** document published prior to the international filing date but later than the priority date claimed**"T"**

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

**"&"**

document member of the same patent family

Date of the actual completion of the international search

22 January 2003 (22.01.2003)

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